OPTIMUM STRUCTURE OF DEPOSITED ULTRA THIN SILICON OXYNITRIDE FILM TO MINIMIZE LEAKAGE CURRENT

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INTRODUCTION

Gate direct tunneling (DT) current is one of the most serious problems in the scaling ULSIs. In order to suppress the DT current with maintaining higher dielectric constant, various CVD processes for forming SiON film with a high nitrogen concentration [1-4] are promising candidates for fabricating gate dielectrics for near-future high performance CMOS technology nodes. However, the gate current in the Si_3N_4 film is higher in PMOS (hole current dominant) than that in NMOS (electron current dominant) [3,4]. These reports suggest that the hole DT current increases due to Si_3N_4 film with low hole barrier height (e.g., the valence band barrier height). Thus, when proposing the SiON film structure which makes leakage current the minimum, it is necessary to clarify the various parameter changes (dielectric constant, barrier height, effective mass) accompanied by film composition change, and the conduction mechanism of the gate leakage current which includes electron and hole conductions. The purpose of this study is to clarify the above parameter changes, the optimum SiON film structure which makes leakage current the minimum, and the origin of the optimum value of film structure.

EXPERIMENTAL

CZ p-type Si(100) substrates were cleaned by HF/ H_2O treatment after RCA, and were placed in a vacuum chamber. Next, thin SiON films were grown on the substrates by SiH_4/ N_2*/ O_2 RPE-CVD process [1], and were annealed at 850 ^oC in N_2 at 1Torr for 30min, sequentially. Using these procedures, we have been able to control the range of oxygen atomic concentration [O] from 0 to 50% inside bulk SiON region. Next, we measured the film composition and the band diagram by *in situ* XPS analysis. Regarding electrical property, we made the MIS capacitor having Au/ SiON/ p-Si/ Au structure, and we performed the J-V and two-frequency C-V measurements [5]. Moreover, we investigated the relation between the electrical effective thickness (T_{eff}) and the leakage current under the same E_{ox} =5MV/cm in gate minus condition.

RESULTS AND DISCUSSIONS

Figure 1 shows the various physical and electrical characteristics as a function of [O] in SiON films. We have already confirmed that the SiON film compositions obey the pseudobinary alloy model; $(Si_3N_4)_x(SiO_2)_{1-x}$ [6]. Furthermore, we have obtained the relationship between the dielectric constant and [O] as shown in Fig.1 (a) [7]. In addition, we measured the barrier heights for electron and hole (b) by using valence band spectra (valence band barrier height) and energy loss spectra of O1s and N1s (band gap) [8,9]. It was found that hole barrier heights between SiON film and p-Si greatly decrease compared with electron barrier heights between Au and SiON film accompanying the decrease of [O] in SiON film. Figure 1(c) shows the normalized leakage current of SiON films. Leakage current is normalized by that of SiO_2 film at the same T_{eff}. It was clearly shown that the leakage current re-increases at [O]=45% (turn-around phenomenon). Thus, optimum [O] in SiON film which makes the leakage current the minimum exists, and a SiO(40%)N film attained an about 2 order reduction in leakage current compared with the SiO_2 film.

In order to clarify the origin of optimum composition of SiON film, we simulated the electron and hole DT currents by using the Simmons equation [10]. The experimental values of dielectric constant (a) and barrier heights (b) were used for the above simulation, and the effective masses were used as fitting parameters. In (c), it is shown that the calculated results of total DT currents are in agreement with the experimental results. From these results, it is clarified that optimum SiON film structure which has the minimum leakage current is decided by the balance of the increase in hole DT current accompanied by the decrease in valence band barrier height and the decrease in electron DT current in accordance with rises of dielectric constant and physical thickness.

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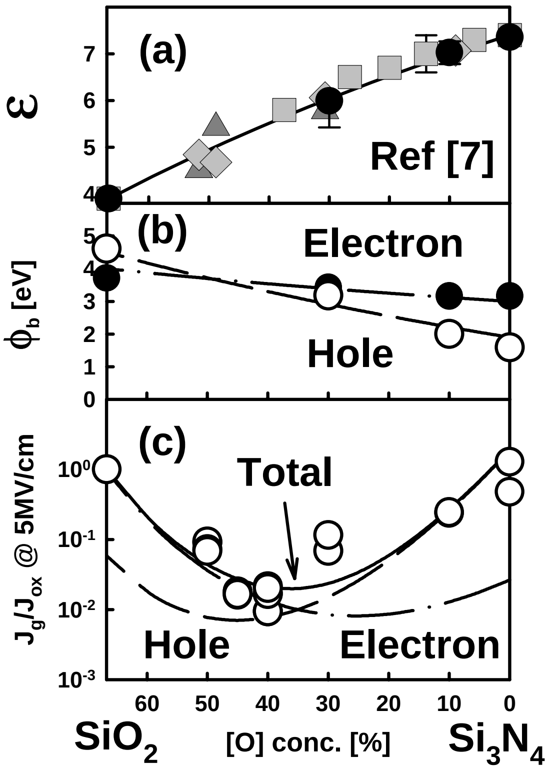

Fig.1 Various physical and electrical characteristics as a function of [O] in SiON films (T_{eff} ~2nm): (a) dielectric constant, (b) barrier heights for electron and hole, (c) normalized leakage currents of electron, hole and total. Circle symbols and lines mean the experimental results and calculated results, respectively.